Lecture 2: The Scanline Algorithm
Announcements
Trying to Add the Class?

• Let’s talk after class...
Canvas is Operational

- Are you getting emails?
- Submit 1A to Canvas...
Questions About Final Projects
From Last Time: Grading

- Project 1: 30 points
- Project G (grad students): 15 points
- Project 2: 15 points
- Proposal for Project 3: 0 points
- Midterm: 25 points
- Project 3: 30 points
Project 1A
Goal: write a specific image
Due: 11:59pm, Sept 30th ... in 84 hours (!)
% of grade: 2%
Q: Why do I only get 3 1/2 days to complete this project?
A: We need to need to get multi-platform issues shaken out ASAP.
May be a little painful
Project #1A: background

• Definitions:
  – Image: 2D array of pixels
  – Pixel: A minute area of illumination on a display screen, one of many from which an image is composed.

• Pixels are made up of three colors: Red, Green, Blue (RGB)

• Amount of each color scored from 0 to 1
  – 100% Red + 100% Green + 0% Blue = Yellow
  – 100% Red + 0% Green + 100% Blue = Purple
  – 0% Red + 100% Green + 0% Blue = Cyan
  – 100% Red + 100% Blue + 100% Green = White
Project #1A: background

• Colors are 0->1, but how much resolution is needed? How many bits should you use to represent the color?
  – Can your eye tell the difference between 8 bits and 32 bits?
  – No. Human eye can distinguish ~10M colors.
  – 8bits * 3 colors = 24 bits = ~16M colors.

• Red = (255,0,0)
• Green = (0,255,0)
• Blue = (0,0,255)
Project #1A: background

• An “M by N” 8 bit image consists of MxNx3 bytes.
  – It is stored as:
    P0/R, P0/G, P0/B, P1/R, P1/G, P1/B, ... P(MxN)/R, P(MxN)/G, P(MxN)/B

• P0 is the top, left pixel
• P(M-1) is the top, right pixel
• P((MxN)-M+1) is the bottom, left pixel
• P(MxN) is the bottom, right pixel
Project #1A: background

- The red contributions are called the “red channel”.
  - Ditto blue & green.
- There are 3 channels in the image described above.
- There is sometimes a fourth channel, called “alpha”
  - It is used for transparency.
- Images are either RGB or RGBA
Project #1A in a nutshell

• Assignment:
  – Install CMake
  – Install VTK
  – Modify template program to output specific image
What is `CMake`?

- Cmake is a cross-platform, open-source build system.
- CMake is a family of tools designed to build, test and package software.
- CMake is used to control the software compilation process using simple platform and compiler independent configuration files.
- CMake generates native makefiles and workspaces that can be used in the compiler environment of your choice.
How do you install CMake?

- Go to [www.cmake.org](http://www.cmake.org) & follow the directions
What is the Visualization Toolkit (VTK)?

• The Visualization Toolkit (VTK) is an open-source, freely available software system for 3D computer graphics, image processing and visualization.

• VTK consists of a C++ class library and several interpreted interface layers including Tcl/Tk, Java, and Python.

• VTK is cross-platform and runs on Linux, Windows, Mac and Unix platforms.
How do you install VTK?

• Go to www.vtk.org, go to Resources-Download and follow the directions
VTK 6 vs VTK 7...
What is the image I’m supposed to make?
What do I do again?

• Install CMake & VTK.
• Download “project1A.cxx” from class website
• Download “CMakeLists.txt” from class website
• Run CMake
• Modify project1A.cxx to complete the assignment
• And...
• Submit to Canvas the source and image result by Friday midnight.
What should you do if you run into trouble?

1) Start with Canvas
2) OH this week:
   ◆ Tues 1pm-2pm, Weds 1pm-2pm
3) Email me: hank@cs.uoregon.edu

Don’t forget: this lecture is available online
What Are We Rendering?

• Models made up of polygons
• Usually triangles
• Lighting tricks make surfaces look non-faceted
• More on this later...
The Scanline Algorithm
Reminder: ray-tracing vs rasterization

• Two basic ideas for rendering: rasterization and ray-tracing

• Ray-tracing: cast a ray for every pixel and see what geometry it intersects.
  – $O(n\text{Pixels})$
    • (actually, additional computational complexity for geometry searches)
  – Allows for beautiful rendering effects (reflections, etc)
  – Will discuss at the end of the quarter
Reminder: ray-tracing vs rasterization

• Two basic ideas for rendering: rasterization and ray-tracing

• Rasterization: examine every triangle and see what pixels it covers.
  – $O(n\text{Triangles})$
    • (actually, additional computational complexity for painting in pixels)
  – GPUs do rasterization very quickly
  – Our focus for the next 5 weeks
What color should we choose for each of these four pixels?
What color should we choose for each of these four pixels?

Most dominant triangle
What color should we choose for each of these four pixels?
What color should we choose for each of these four pixels?
What color should we choose for each of these four pixels?
The middle and lower-left variants are half-pixel translations of the other pixel. We will use the lower-left convention for the projects.
Where we are...

• We haven’t talked about how to get triangles in position.
  – Arbitrary camera positions through linear algebra
• We haven’t talked about shading
• Today, we are tackling this problem:
  How to deposit triangle colors onto an image?
Problem: how to deposit triangle colors onto an image?

• Let’s take an example:
  – 12x12 image
  – Red triangle
    • Vertex 1: (2.5, 1.5)
    • Vertex 2: (2.5, 10.5)
    • Vertex 3: (10.5, 1.5)
    • Vertex coordinates are with respect to pixel locations
Our desired output

How do we make this output? Efficiently?
Don’t need to consider any pixels outside these lines.
Scanline algorithm: consider all rows that can possibly overlap.

Don't need to consider any pixels outside these lines.
Scanline algorithm: consider all rows that can possibly overlap.

We will extract a “scanline”, i.e. calculate the intersections for one row of pixels.
- Red triangle
  - Vertex 1: (2.5, 1.5)
  - Vertex 2: (2.5, 10.5)
  - Vertex 3: (10.5, 1.5)
– Red triangle
  • Vertex 1: (2.5, 1.5)
  • Vertex 2: (2.5, 10.5)
  • Vertex 3: (10.5, 1.5)
– Red triangle
  • Vertex 1: (2.5, 1.5)
  • Vertex 2: (2.5, 10.5)
  • Vertex 3: (10.5, 1.5)

What are the end points?
Red triangle
- Vertex 1: (2.5, 1.5)
- Vertex 2: (2.5, 10.5)
- Vertex 3: (10.5, 1.5)
- Red triangle
  - Vertex 1: (2.5, 1.5)
  - Vertex 2: (2.5, 10.5)
  - Vertex 3: (10.5, 1.5)

What are the end points?

Y=5

(2.5, 5)

Algebra!
- Red triangle
  - Vertex 1: (2.5, 1.5)
  - Vertex 2: (2.5, 10.5)
  - Vertex 3: (10.5, 1.5)
- \( Y = mx + b \)
- \( 10.5 = m \times 2.5 + b \)
- \( 1.5 = m \times 10.5 + b \)
- \( \Rightarrow \)
- \( 9 = -8m \)
- \( m = -1.125 \)
- \( b = 13.3125 \)
- \( 5 = -1.125 \times x + 13.3125 \)
- \( x = 7.3888 \) (2.5, 5)

What are the end points?
Scanline algorithm: consider all rows that can possibly overlap.

Don’t need to consider any Pixels outside these lines.

Y=5

2.5

7.3888
Scanline algorithm: consider all rows that can possibly overlap

Don't need to consider any pixels outside these lines

Color is deposited at (3,5), (4,5), (5,5), (6,5), (7,5)
Scanline algorithm

• Determine rows of pixels triangles can possibly intersect
  – Call them rowMin to rowMax
    • rowMin: ceiling of smallest Y value
    • rowMax: floor of biggest Y value
• For r in [rowMin \rightarrow rowMax] ; do
  – Find end points of r intersected with triangle
    • Call them leftEnd and rightEnd
  – For c in [ceiling(leftEnd) \rightarrow floor(rightEnd)] ; do
    • ImageColor(r, c) \leftarrow triangle color
Scanline algorithm

• Determine rows of pixels triangles can possibly intersect
• For \( r \) in \([\text{rowMin} \rightarrow \text{rowMax}]\) ; do
  – Find end points of \( r \) intersected with triangle
    • Call them leftEnd and rightEnd
  – For \( c \) in \([\text{ceiling}(\text{leftEnd}) \rightarrow \text{floor}(\text{rightEnd})]\) ; do
    • ImageColor\((r, c)\) \(\leftarrow\) triangle color

For \( r = 5 \), we call ImageColor with \((5,3), (5,4), (5,5), (5,6), (5,7)\)

Y values from 1.5 to 10.5 mean rows 2 through 10

For \( r = 5 \), leftEnd = 2.5, rightEnd = 7.3888
Arbitrary Triangles

• The description of the scanline algorithm in the preceding slides is general.
• But the implementation for these three triangles vary:
Supersampling: use the scanline algorithm a bunch of times to converge on the “average” picture.
Where we are...

• We haven’t talked about how to get triangles into position.
  – Arbitrary camera positions through linear algebra
• We haven’t talked about shading
• Today, we tackled this problem:
  How to deposit triangle colors onto an image?
  Still don’t know how to:
  1) Vary colors (easy)
  2) Deal with triangles that overlap
Project 1B
Arbitrary Triangles

• You will implement the scanline algorithm for triangles with “flat bottoms”
Project #1B

• Goal: apply the scanline algorithm to “flat bottom” triangles and output an image.
• File “project1B.cxx” has triangles defined in it.
• Due: Weds, Oct. 5th
• % of grade: 6%
Project #1C

• You will implement the scanline algorithm for arbitrary triangles ... plan ahead
Tips On Floating Point Precision
Project 1B

• Cout/cerr can be misleading:

```c
fawcett:Downloads child$ cat t2.C
#include <iostream.h>
#include <iomanip>

int main()
{
    double X=188;
    X-=1e-12;
    cerr X << endl;
    cerr std::setprecision(16) X << endl;
}
fawcett:Downloads child$ ./a.out
188
187.999999999999
Project 1B

• The limited accuracy of cerr/cout can cause other functions to be appear to be wrong:

```cpp
#include <iostream.h>
#include <iomanip>
#include <math.h>

int main() {
    double X=188;
    X-=1e-12;
    cerr << "The floor of " << X << " is " << floor(X) << endl;
}
```

```
fawcett:Downloads childs$ cat t3.C
The floor of 188 is 187
```
Project 1B

• Floating point precision is an approximation of the problem you are trying to solve
• Tiny errors are introduced in nearly every operation you perform
  – Exceptions for integers and denominators that are a power of two
• Fundamental problem:
  – Changing the sequence of these operations leads to *different* errors.
  – Example: \((A+B)+C \neq A+(B+C)\)
Project 1B

• For project 1B, we are making a binary decision for each pixel: should it be colored or not?
• Consider when a triangle vertex coincides with the bottom left of a pixel:

• We all do different variations on how to solve for the endpoints of a line, so we all get slightly different errors.
Project 1B

- Our algorithm incorporates floor and ceiling functions.
  - This is the right place to bypass the precision problem.
  - I have included “floor441” and “ceil441” in project prompt. You need to use them, or you will get one pixel differences.
Project 1B: other thoughts

• You will be building on this project ...
  – think about magic numbers (e.g. screen size of 1000)
  – add safeguards against cases that haven’t shown up yet
  – Assume nothing!